Higgs mechanism as a magnetic picture of dynamical symmetry breaking

Ryuichiro Kitano (Tohoku U.)

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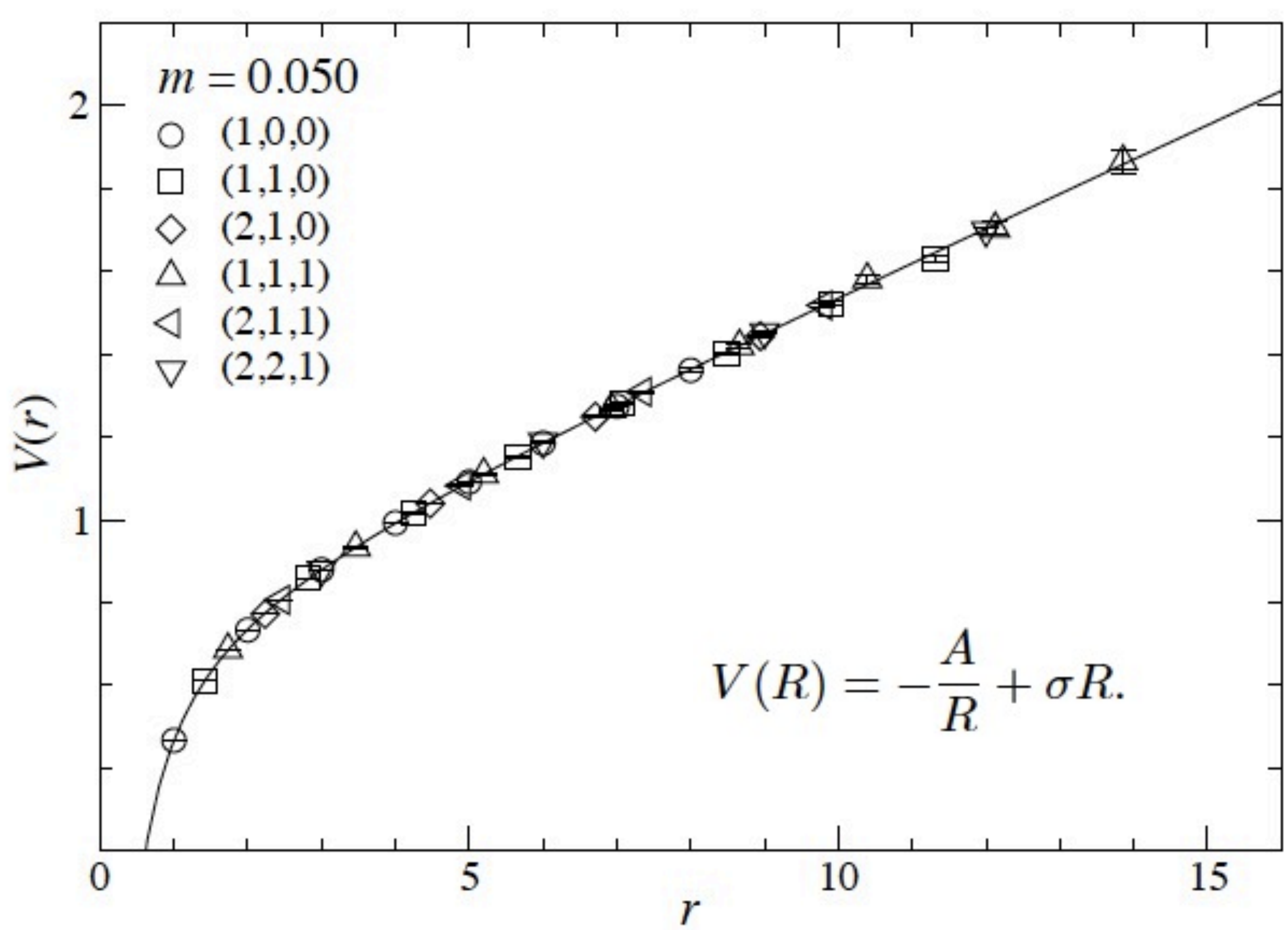
Higgs at 125GeV

What is this?

I try to approach to this question from the quark confinement in QCD.

Quark Confinement

Quarkonium mass spectrum and lattice simulations both support the Coulomb+linear type potential model for the static quark anti-quark system.



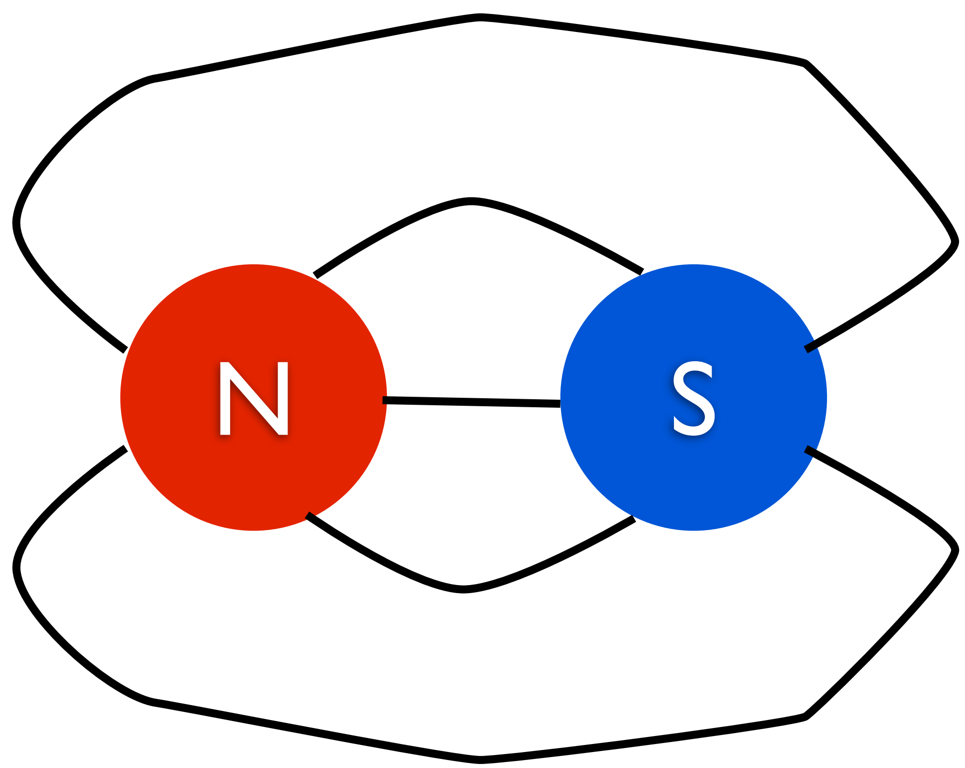
[JLQCD '08]

Why?

There is a pretty simple picture.

Confinement is dual to Higgs mechanism, and in the dual picture, the quarks are magnetic monopoles.

[Mandelstam '75, 't Hooft '75]



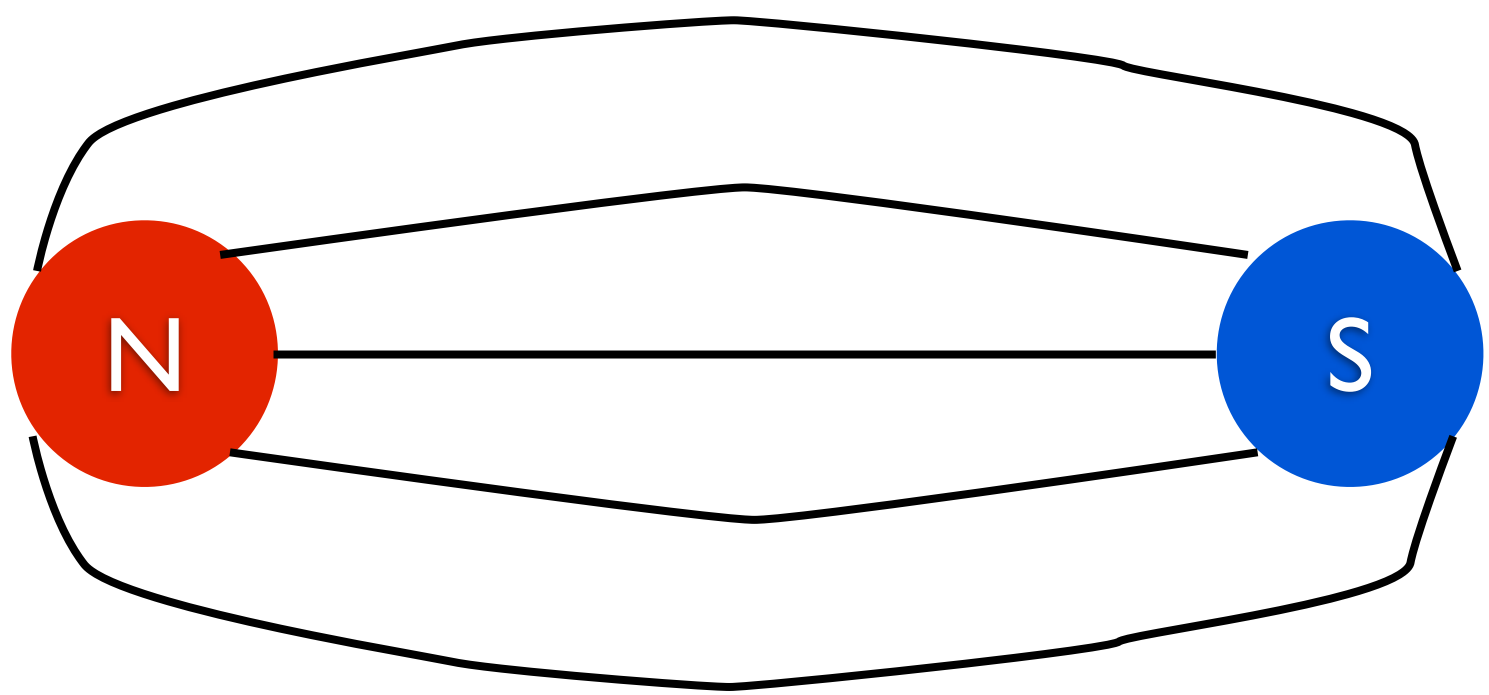
Coulomb like

Why?

There is a pretty simple picture.

Confinement is dual to Higgs mechanism, and in the dual picture, the quarks are magnetic monopoles.

[Mandelstam '75, 't Hooft '75]



Why?

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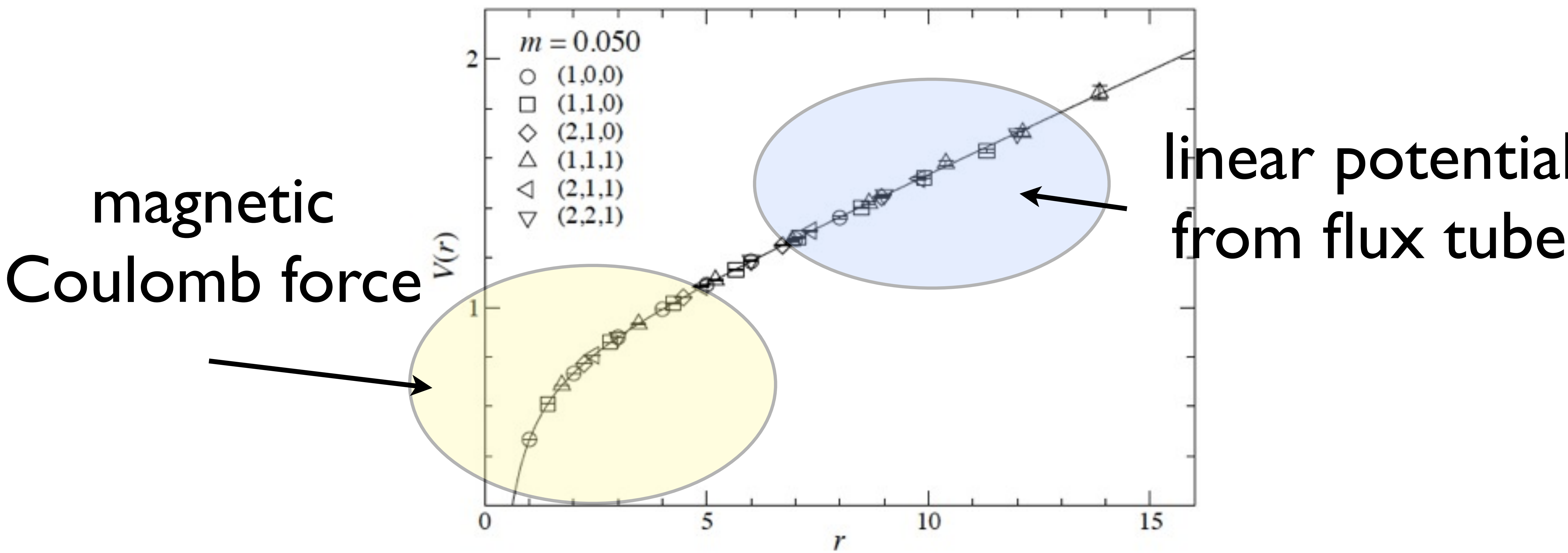
Confinement is dual to Higgs mechanism, and in the dual picture, the quarks are magnetic monopoles.

[Mandelstam '75, 't Hooft '75]

Linear potential

This mechanism provides us with a classical picture for the quark confinement.



$$V(R) = -\frac{A}{R} + \sigma R. \qquad A \sim 0.25 - 0.5, \quad \sqrt{\sigma} \sim 430 \text{ MeV}.$$

If there is such a classical picture,

Where is the magnetic gauge boson in QCD?

There are massive vector mesons $\rho(770)$, $\omega(782)$.

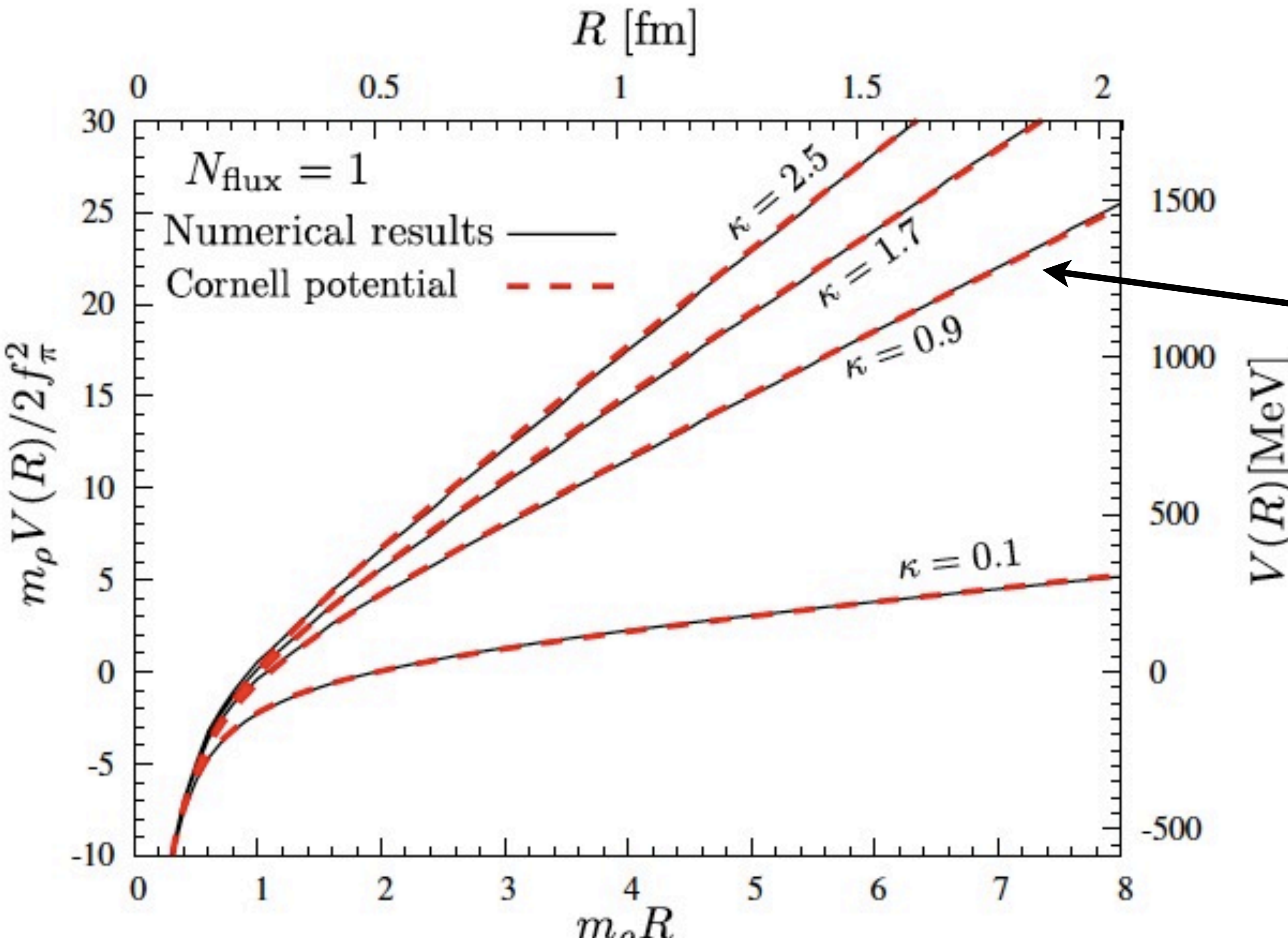
If there is such a classical picture,

Where is the magnetic Higgs boson in QCD?

There are massive scalar mesons $\sigma(600)$, $f_0(980)$.

We constructed a model of $\rho/\omega/f_0/a_0$ system as a Higgsed gauge theory, and calculated the energy of the monopole-antimonopole system.

[RK, Nakamura, Yokoi '12]



this line

$A = 0.25$

$\sqrt{\sigma} = 400$ MeV

$$V(R) = -\frac{A}{R} + \sigma R.$$

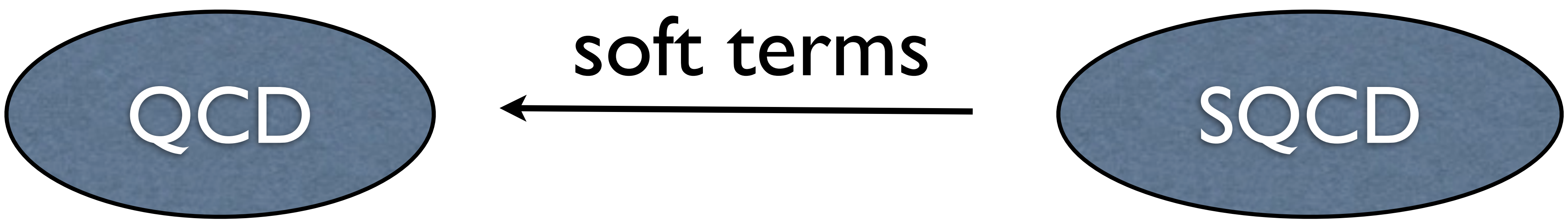
We could reproduce the QCD potential.

Can we derive the magnetic model from QCD?

It's difficult. But I will try here by using electric-magnetic duality in SUSY QCD.

QCD from SQCD

QCD can be obtained by adding soft mass terms for the gaugino and squarks.



QCD from SQCD

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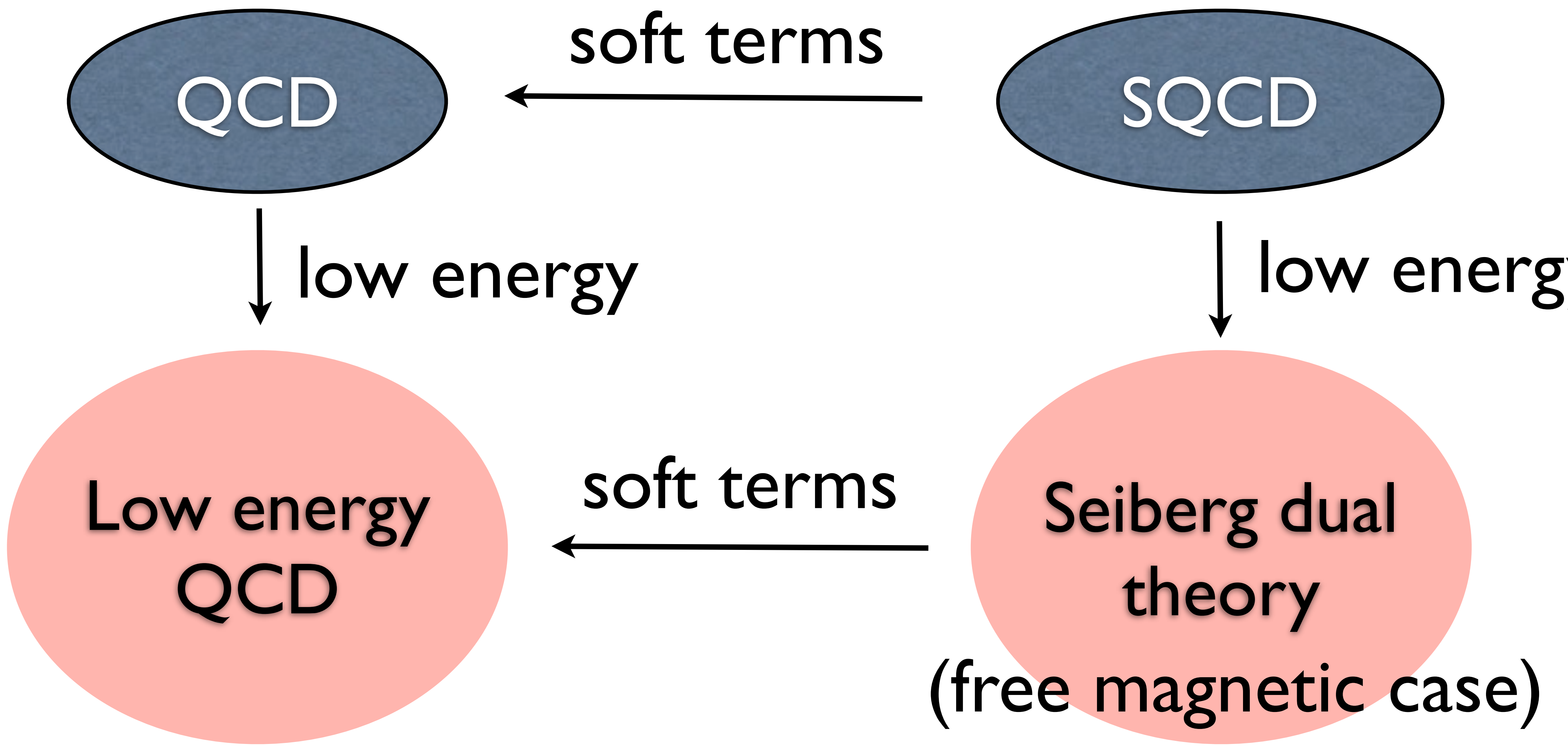

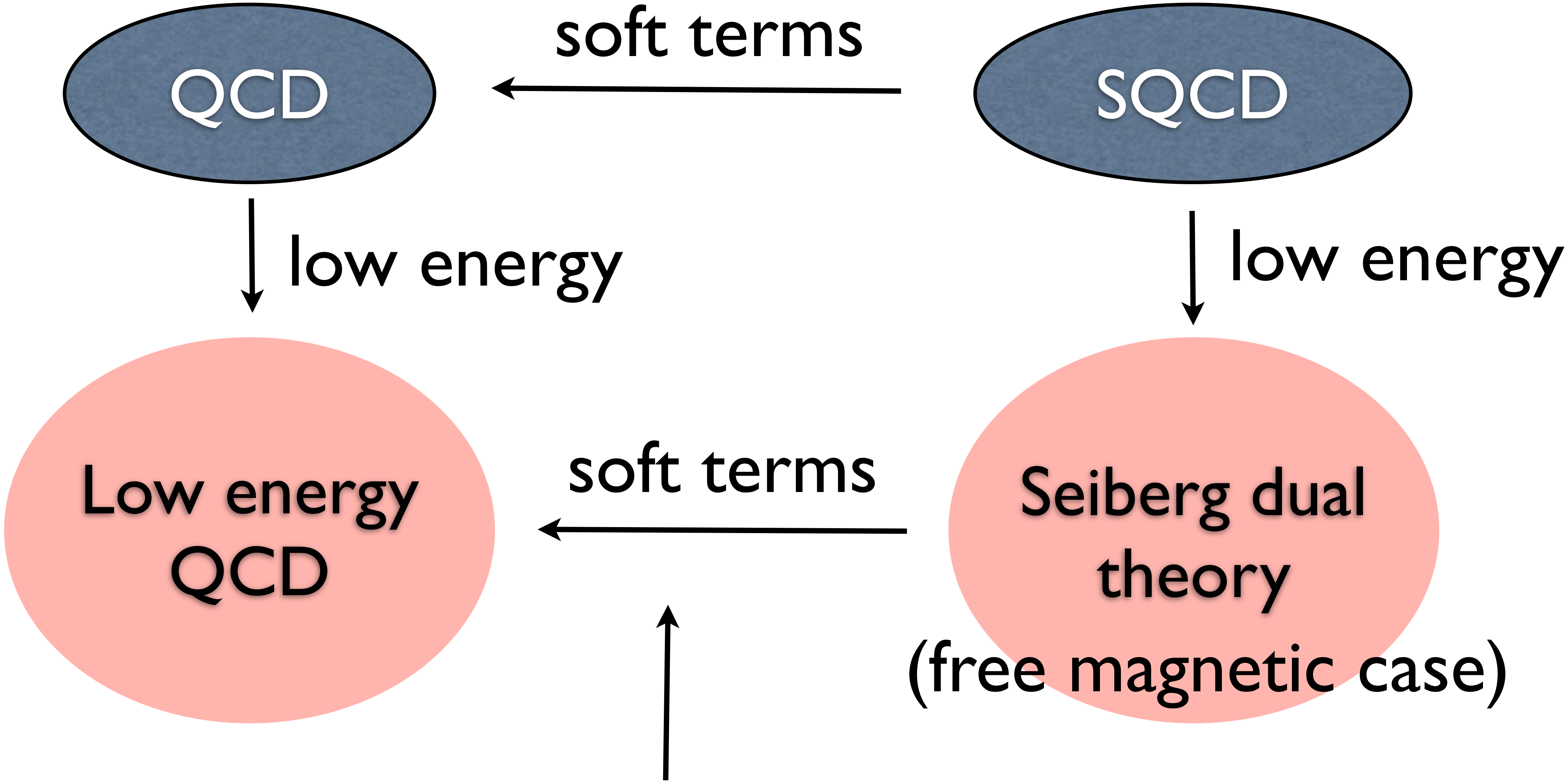

The question is the smoothness of this limit.
[Aharony, Sonnenschein, Peskin, Yankielowicz '95]

And unfortunately, it has been shown that it is **not smooth** based on the Vafa-Witten theorem.

[Arkani-hamed, Rattazzi '98]

The problem was the spontaneous $U(1)_B$ breaking due to tachyonic soft masses for the squarks.

Actually, one can easily evade this.

model

	$SU(N_c)$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_B$	$SU(N_c)_V$	$U(1)_{B'}$	$U(1)_R$
Q	N_c	N_f	1	1	1	0	$(N_f - N_c)/N_f$
$\overline{Q}$	$\overline{N_c}$	1	$\overline{N_f}$	-1	1	0	$(N_f - N_c)/N_f$
Q'	N_c	1	1	0	$\overline{N_c}$	1	1
$\overline{Q}'$	$\overline{N_c}$	1	1	0	N_c	-1	1

auxiliary massive flavors

$W = mQ'\bar{Q}'$ (mass term for the auxiliary flavors)

$$\mathcal{L}_{\text{soft}} = -\tilde{m}^2(|Q|^2 + |\bar{Q}|^2 + |Q'|^2 + |\bar{Q}'|^2) - \left(\frac{m_\lambda}{2}\lambda\lambda + \text{h.c.}\right) - (BmQ'\bar{Q}' + \text{h.c.})$$

(soft SUSY breaking terms)

magnetic picture

	$SU(N_f)$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_B$	$SU(N_c)_V$	$U(1)_{B'}$	$U(1)_R$
q	N_f	$\overline{N_f}$	1	0	1	N_c/N_f	N_c/N_f
$\overline{q}$	$\overline{N_f}$	1	N_f	0	1	$-N_c/N_f$	N_c/N_f
Φ	1	N_f	$\overline{N_f}$	0	1	0	$2(N_f - N_c)/N_f$
q'	N_f	1	1	1	N_c	$-(N_f - N_c)/N_f$	0
$\overline{q}'$	$\overline{N_f}$	1	1	-1	$\overline{N_c}$	$(N_f - N_c)/N_f$	0
Y	1	1	1	0	$1 + \text{Adj.}$	0	2
Z	1	1	$\overline{N_f}$	-1	$\overline{N_c}$	1	$(2N_f - N_c)/N_f$
$\overline{Z}$	1	N_f	1	1	N_c	-1	$(2N_f - N_c)/N_f$

$$\begin{aligned}\mathcal{L}_{\text{soft}} &= -\tilde{m}_q^2(|q|^2 + |\bar{q}|^2 + |q'|^2 + |\bar{q}'|^2) - \tilde{m}_M^2(|Y|^2 + |Z|^2 + |\bar{Z}|^2 + |\Phi|^2) \\ &\quad - \left(\frac{m_{\tilde{\lambda}}}{2}\tilde{\lambda}\tilde{\lambda} + \tilde{B}m\Lambda Y + Ah\left(q'Y\bar{q}' + q'Z\bar{q} + q\bar{Z}\bar{q}' + q\Phi\bar{q}\right) + \text{h.c.}\right).\end{aligned}$$

$$Y = -\frac{\tilde{B}m\Lambda}{\tilde{m}_M^2}.$$

split into two sectors.

Hidden Local Symmetry

	$SU(N_f)$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_B$	$SU(N_c)_V$	$U(1)_{B'}$	$U(1)_R$
q	N_f	$\overline{N_f}$	1	0	1	N_c/N_f	N_c/N_f
$\overline{q}$	$\overline{N_f}$	1	N_f	0	1	$-N_c/N_f$	N_c/N_f
Φ	1	N_f	$\overline{N_f}$	0	1	0	$2(N_f - N_c)/N_f$
q'	N_f	1	1	1	N_c	$-(N_f - N_c)/N_f$	0
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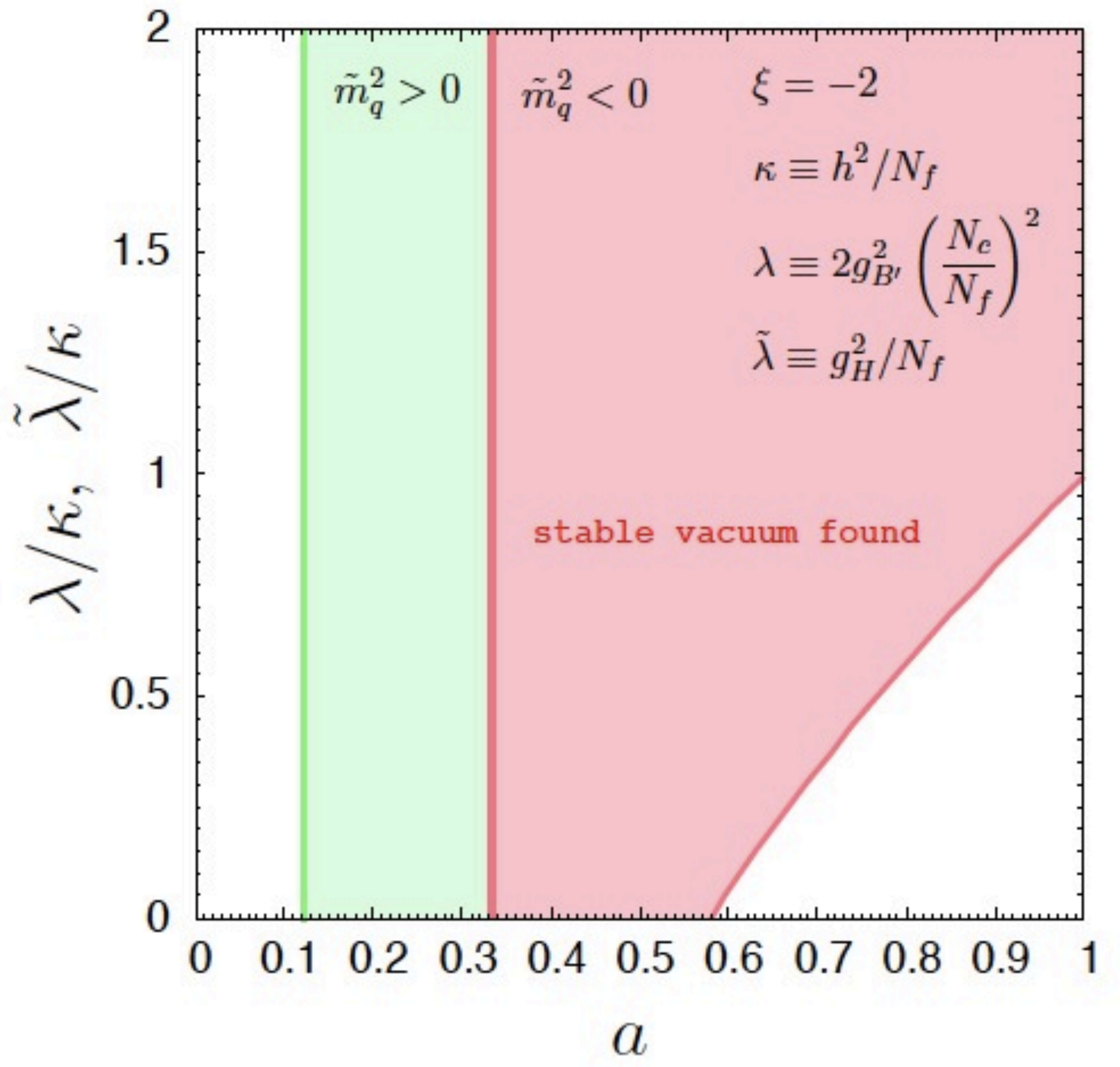
This sector has the same structure as the HLS.

$$q = \bar{q} = v\mathbf{1} \neq 0, \quad \Phi = v_\Phi \mathbf{1} \neq 0,$$

break chiral symmetry and give masses to magnetic gauge bosons (ρ meson) while leaving $U(1)_B$ symmetry unbroken.

Indeed,



one can find such a vacuum is realized in a large region of the parameter space.

I think SQCD is smoothly connected to QCD through the mass deformed Nf+Nc flavor theory.

↓

If that's the case,

chiral symmetry breaking = magnetic Higgs mechanism

= confinement

ρ meson is the magnetic gauge boson!

[Seiberg '95, Harada, Yamawaki '99, Komargodski '10, RK '11, Abel, Barnard '12]

so?

Electroweak symmetry breaking may be similar.
Namely, the SM may be the magnetic picture of some fundamental theory.

[Seiberg '95, Maekawa'96, Strassler '96, ..., RK, Fukushima, Yamaguchi '10
Craig, Stolarsky, Thaler '11, Csaki, Shirman, Terning '11, Csaki, Randall, Terning '11]

I think it is very important to look for
a magnetic gauge boson (vector resonance) next
at the LHC!

electroweak physics is similar?

Higgs = composite field

= Magnetic degree of freedom?

= dual to some dynamical system

But we know that theories too similar to QCD will not be good, since that's just the QCD-like technicolor paradigm.

$\longrightarrow$ We need a light Higgs boson.

$\longrightarrow$ SUSY is now essential. It's not just a tool.

model building

	$SU(N_c)$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_B$	$SU(N_c)_V$	$U(1)_{B'}$	$U(1)_R$
Q	N_c	N_f	1	1	1	0	$(N_f - N_c)/N_f$
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$$W = mQ'\bar{Q}'$$

$$\mathcal{L}_{\text{soft}} = -\tilde{m}^2(|Q|^2 + |\bar{Q}|^2 + |Q'|^2 + |\bar{Q}'|^2) - \left(\frac{m_\lambda}{2}\lambda\lambda + \text{h.c.}\right) - \left(BmQ'\bar{Q}' + \text{h.c.}\right)$$

As the first trial, I consider the very same model as the one used for QCD.

model

Nc=3, Nf=2

embed $SU(2)_L x U(1)_Y$

	$SU(N_c)$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_B$	$SU(N_c)_V$	$U(1)_{B'}$	$U(1)_R$
Q	N_c	N_f	1	1	1	0	$(N_f - N_c)/N_f$
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Q'	N_c	1	1	0	$\overline{N_c}$	1	1
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anomalous?

model

Nc=3, Nf=2

embed $SU(2)_L \times U(1)_Y$ embed SU(3)c

	$SU(N_c)$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_B$	$SU(N_c)_V$	$U(1)_{B'}$	$U(1)_R$
Q	N_c	N_f	1	1	1	0	$(N_f - N_c)/N_f$
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Q'	N_c	1	1	0	$\overline{N_c}$	1	1
$\overline{Q}'$	$\overline{N_c}$	1	1	0	N_c	-1	1

anomalous?

$\longrightarrow$ Subtract top+bottom (and Higgs) from the MSSM

model

Nc=3, Nf=2

embed $SU(2)_L$x$U(1)_Y$ embed SU(3)c

	$SU(N_c)$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_B$	$SU(N_c)_V$	$U(1)_{B'}$	$U(1)_R$
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Q'	N_c	1	1	0	$\overline{N_c}$	1	1
$\overline{Q}'$	$\overline{N_c}$	1	1	0	N_c	-1	1

top+bottom (but colored under different SU(3))

This is the super-topcolor model.

[RK, Fukushima, Yamaguchi ’10]

In fact, SU(3) 5 flavor theory is in the conformal window:

$$3N_C/2 < N_f < 3N_C$$

$$\longrightarrow \quad 4.5 < N_f < 9 \quad \text{for} \quad N_c = 3$$

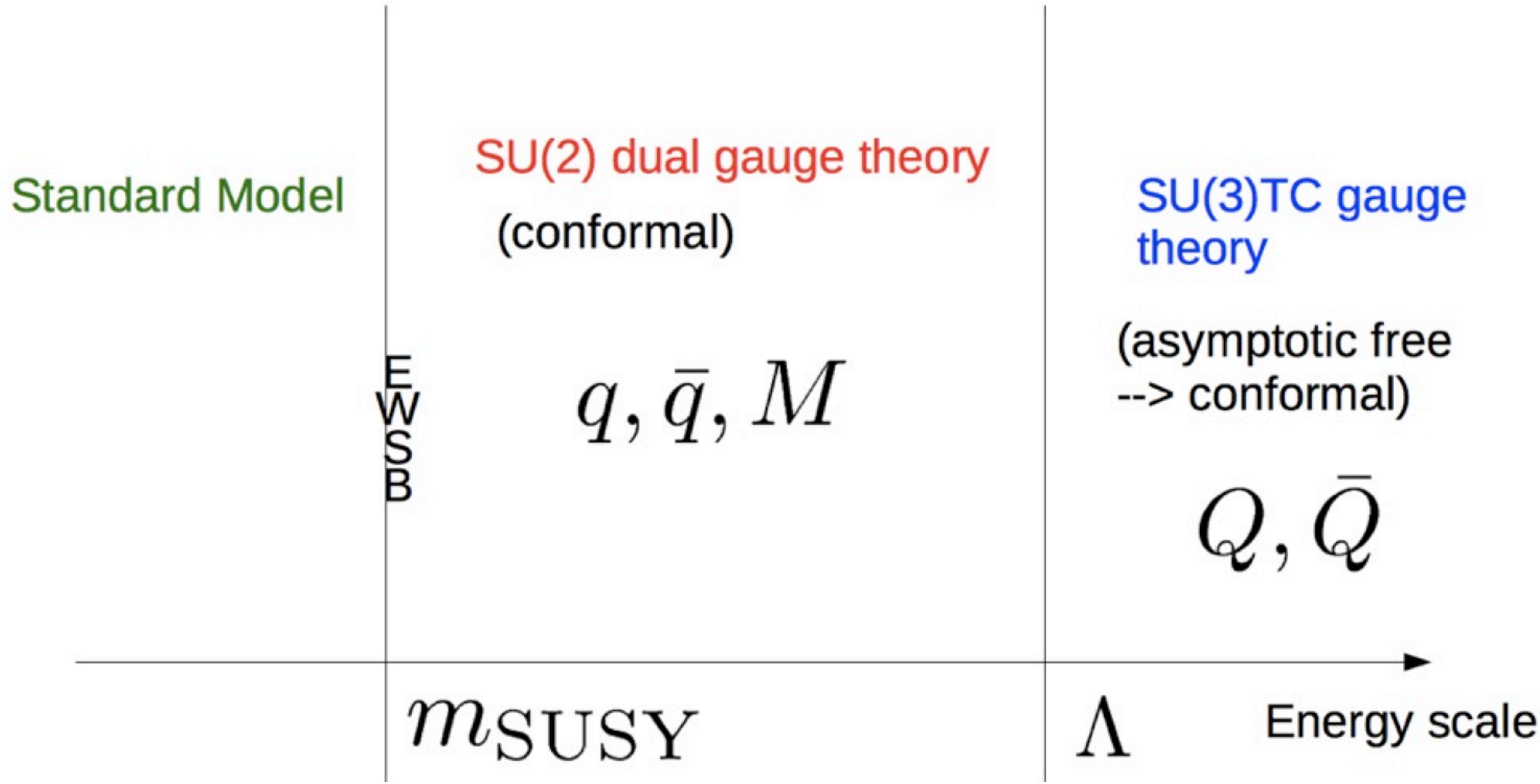
N_f=5 is at the most strongly coupled point in the conformal window.

This means the Seiberg dual theory is at the most weakly coupled point in the conformal window.

$\longrightarrow$ One can do perturbative calculation (expansion in terms of $1/N_f$)

(particle picture in the dual theory)

Weakly coupled descriptions



dual theory

We obtain the MSSM coupled to weakly coupled CFT.

Higgs sector!

SU(2)LxU(1)Y

SU(3)c

	$SU(N_f)$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_B$	$SU(N_c)_V$	$U(1)_{B'}$	$U(1)_R$
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top+bottom quarks! (they now have color)

Sketch

- Higgs mass can be enhanced by a coupling to the CFT sector (next talk).
- stop mass has IR fixed point at zero when we ignore the gluino mass and D-terms. The stop is naturally light, and it is good for naturalness.

Summary

- A possible smooth path from SQCD to QCD is found.
- The ρ meson can be interpreted as the magnetic gauge boson.
- The Higgs mechanism in the SM may also be the magnetic picture.
- I think it is very important to look for a vector resonance! (We now have a huge room for the S parameter because of the light Higgs boson!)